8. REFERENCES

1. H. Hahn, Editor, RHIC Design Manual
2. M. Iarocci, "Calculation of Oxygen Deficiency Hazard Classes for RHIC," Tech Note AD/RHIC/RD-72, August, 1994
3. M. Plotkin, "RHIC Preliminary Safety Analysis Report," June, 1991.
4. K. C. Wu, "Pressure Relief for RHIC Cryogenic System," RHIC Project Tech. Note AD/RHIC/RD-64, December, 1993
5. K. C. Wu, et al, "An Experimental Study of Catastrophic Loss of Vacuum for RHIC DRD-009 in MAGCOOL," RHIC Project Tech Note AD/RHIC/RD-50, December 1992.
6. K. C. Wu, et al, "An Experimental Study Using Helium to Produce a Catastrophic Loss of Vacuum in a RHIC Dipole Magnet Cryostat," RHIC Project Tech. Note AD/RHIC/RD-54, February 1993.
7. K. C. Wu, "Safety Relief for RHIC Vacuum Tank," RHIC Project Tech. Note AD/RHIC/RD-71, August 1994.
8. J. E. Jensen, et al, "Brookhaven National Laboratory Selected Cryogenic Data Notebook," BNL Report 10200-R, Vol II, Revised August 1980.
9. K. C. Wu, "Thermal Behavior of MAGCOOL Cryogenic System during Quenches of RHIC 009", RHIC Project Technical Note AD/RHIC/RD-29, October 1991.
10. D. P. Brown, "Calculated Volume for the RHIC Magnet Enclosure", RHIC Project Technical Note AD/RHIC/RD-78, November 1994.
11. K. C. Wu, "Estimation of Helium Discharge Rates for RHIC ODH Calculations", RHIC Project Technical Note AD/RHIC/RD-79, November 1994.
12. T. W. Armstrong and R. G. Alsmiller, Jr., ORNL-TM-2498, 1969.
13. RHIC Design Manual, Revision 0, Brookhaven National Laboratory, October 1990.
14. J. D. Cossairt, et al, "Radiation Measurements in the Labyrinth Penetration at a High Energy Proton Accelerator," Health Physics 49 907-917, 1985.

15. U.S. Department of Energy Radiological Control Manual, Washington, D.C., USDOE Report No. N5486.6, June 1992.
16. "Variante du Programme ZEUS Applique a des Problemes de Tunnels," C.E.N. Fontenay-aux-roses, Note CEA-N-933, 1968.
17. Peter J. Gollon and M. A. Awschalom, "Design of Penetrations in Hadron Shields," IEEE Trans. Nucl. Sci. NS-18 741, 1971. Also appears in a longer form in Proc. Intl. Conf. Protection against Accel. and Space Radiation, CERN 71-16, pp. 697-713, 1971.
18. K. Goebel, et al, "Evaluating Dose Rates Due to Neutron Leakage Through the Access Tunnels of the SPS," CERN LABII-RA/Note/75-10, 1975.
19. Peter J. Gollon, "Dosimetry and Shielding Factors Relevant to the Design of Iron Beam Dumps," Fermilab TM-664, 1976.
20. Peter J. Gollon, "Electronics in the Isabelle Tunnel," BNL Isabelle Technical Note 82.
21. Peter J. Gollon and W. Robert Casey, "Isabelle Shielding Criteria and Design," Health Physics 46, 123-132, 1984.
22. M. Harrison and A. J. Stevens, "Beam Loss Scenario at RHIC," AD/RHIC/RD-52, January 1993.
23. NBS-63. "Protection Against Neutron Radiation up to 30 Million Electron Volts," U.S. N.B.S. Handbook 63, April 1967.
24. J. T. Routti and M. H. Van De Voorde, "Estimates of Neutron Leakage Through Penetrations of the CERN Intersecting Storage Rings by Monte Carlo Albedo Calculations," Nucl. Eng. and Design 34 293-305, 1975.
25. G. R. Stevenson, "Dose Equivalent per Star in Hadron Cascade Calculations," CERN Report TIS-RP/173, May 1986.
26. Alan J. Stevens, "Radioisotope Production in air and soil in RHIC," BNL AD/RHIC-29, 1987.

27. G. R. Stevenson, "Neutron Attenuation in Labyrinths, Ducts and Penetrations at High-Energy Proton Accelerators," CERN TIS-RP/182/CF, 5 Jan. 1987; paper presented to ANS Topical Conference on Theory and Practices in Radiation Shielding, Knoxville, TN, 22-24 April, 1987.
28. Graham R. Stevenson and Alberto Fasso, "A comparison of a MORSE Calculation of Attenuation in a Concrete-Lined Duct with Experimental Data from the CERN PS," CERN TIS-RP/185/CF, 1987.
29. G. R. Stevenson, "Dose Equivalent Per Star in Hadron Cascade Calculations," CERN Report TIS-RP/173, 1988.
30. Alan J. Stevens, private communication.
31. Alan J. Stevens, "Analysis of Radiation Levels Associated with Operation of the RHIC Transfer Line," Draft Version 5, September 28, 1992.
32. Alan J. Stevens, "Local Shielding Requirements for the STAR Detector," RHIC/DET Note 5, 1992.
33. Alan J. Stevens, "An Approximate Method for Evaluating Neutron Punch Through in Certain Classes of Shielding Penetrations," AD/RHIC/RD-65, January 1994. Note that Stevens discussion divides this component into two components according to the type of radiation they represent (*high energy particles* which would not have exited the shield if it had not been weakened by the penetration, and *evaporation neutrons* from the wall of the penetration), and does not directly address the radiation streaming down the penetration. Thus his components are not the same as those discussed here.
34. K. Tesch, "The Attenuation of the Neutron Dose Equivalent in a Labyrinth through an Accelerator Shield," *Particle Accelerators* 12, 169-175, 1982.
35. A Van Ginneken, "CASIM: Program to Simulate Transport of Hadronic Cascades in Bulk Matter," Fermilab Report FN-72, 1975.
36. H. G. Vogt, "Monte Carlo Calculations of the Neutron Transmission Through the Access Ways of the Cern Super Proton Synchrotron," CERN 75-14, 1975.

37. S. Musolino, private communication.

38. A. Van Ginneken, "CASIM; Program to Simulate Hadron Cascades in Bulk Matter," Fermilab FN-272, 1975.

39. A. J. Stevens, "Improvements in CASIM; Comparison with Data," AGS/AD/Tech. Note No. 296, 1988.

40. J. Claus and H. Foelsche, "Beam Transfer from AGS to RHIC," AD/RHIC-47, 1988. [Although not explicitly discussed in this reference, the Transfer Line beam elevation is slightly over 1 ft higher than the tunnel center line. No correction for this fact is made for the calculations presented in this note although dose to a person should be evaluated at approximately "the middle" of a person which is typically 3 ft away from the berm for a person standing thereon. Thus ignoring this difference is a conservative assumption.]

41. K. Tesch and H. Dinter, "Estimation of Radiation Fields at High Energy Proton Accelerators," Radiation Protection Dosimetry Vol. 15, No. 2, p.89, 1986.

42. A. Van Ginneken and M. Awschalom, "High Energy Interactions in Large Targets," Fermilab, Batavia, IL., 1975.

43. The conversion is valid in soil at depths greater than a few interaction lengths in the lateral direction where the energy spectrum is in equilibrium and is not valid at any depth for pure Fe shielding. For BNL soil ($\rho = 1.8$ g/cm^3) L = 53.28 cm.

44. G. R. Stevenson, "Dose Equivalent per Star in Hadron Cascade Calculations," CERN Report TIS-RP/173, 1988.

45. A. Van Ginneken and N. Mokhov, private communications.

46. Using the original calibration, a deep penetration lateral shielding measurement in the D-line of the AGS of 126 mrem/hr compares to the CASIM prediction of 65±19 mrem/hr. Details of this comparison are given in a memorandum from A. J. Stevens to D. Beavis dated 12/4/91. Again using this calibration for the measurement reported in Reference 2 predicts 60±5 mrem/hr compared to a measured 48±11 mrem/hr.

47. Radiological Control Manual, Brookhaven National Laboratory, 1995.

48. Aerial survey of April 3, 1991 prepared by Chas. H. Sells, Inc. The aerial survey map shows 2 ft elevation contours.

49. Recall that these estimated dose rates have the neutron quality factor doubled from current standards.

50. The attenuation length for soil derived from Figures 2 and 3 is about 67 cm of soil or 120.6 g/cm^2. This gives a dose reduction factor of about 1.57 per ft of soil. A 14% reduction is derived by replacing 1 ft of soil with 1 ft of soil-equivalent material whose density is 2.4 g/cm^3 instead of 1.8 g/cm^3.

51. "High Occupancy" is defined to be any region occupied more than ½ hour per day (1/16 of an 8 hour day) by a given individual. Occupancy is discussed more fully in Appendix 1.

52. A 1/R attenuation is an appropriate short distance extrapolation for a line source of loss which is most often encountered in "beam scraping" losses at accelerators. Combining this fall-off with the nearly point-loss sources assumed is somewhat conservative but is adopted here to compensate for "groundshine" which, although discussed in section 7 of this note, is usually neglected.

53. C. Distenfeld and R. Colvett, "Skyshine Considerations for Accelerator Shielding Design," Nucl. Sci. Eng. Vol. 26, p.117, 1966. The expression given in this reference has been multiplied by 2 because skyshine is dominantly low energy neutrons and we are assuming double the current quality factor.

54. The equilibrium spectrum used to "calibrate" CASIM (Reference 5) is well represented by the following: $E^{-1.4}$ for E >7 MeV, $.19887XE^{-.57}$ for 0.1 MeV <E <7 MeV, $.07389XE^{-1}$ for E <0.1 MeV.

55. The numerical loss values given in sections 3 and 4 have been doubled which corresponds to the total (0.1% for normal losses) loss over the length of the Transfer Line. An Au ion is taken to be equivalent to 197×10.4/28 protons.

56. E. Lessard, private communication. The methodology employed in the text was previously developed by Lessard.

57. Evaporation neutrons, of order 1 MeV, are isotropic, while intra-nuclear cascade neutrons, of order 10 MeV, are generally not.

58. The induced activity has been estimated to be of the order of 1.5 mrem/hr at 1 ft from the side of the dump following a one hour cooling period and about 10 times this at 1 ft from the downstream end. This estimate will be documented elsewhere.

59. In these calculations the (correct) beam elevation shown in Figure 12 implies that the value of R corresponding to 86 ft elevation is 5.1 m. Compare to footnote 5 above.

60. The expression for the total neutron flux is the same as that given in section 6 with the exceptions that the correction to 20 MeV is 1.46 for Au ions and the radius is 510 cm.

61. The collimator is approximated by a section of steel 25 cm long at a lateral distance >1 cm within a 1.6 cm inner radius vacuum pipe. Interactions are forced to occur uniformly along the length at a 1 mm distance into the steel, i.e., at X = 1.1 cm, Y = 0, 0 <Z <25 cm. For convenience, the steel (Fe) shielding was assumed between R = 17 cm and R = 47 cm.

62. This result follows from considering an Au ion at 10.4 GeV/u to be equivalent to 124 28 GeV protons. This equivalence follows from comparison of the maximum star densities shown in Figures 2 and 3, and corresponds (approximately) to $\sqrt{E}$ scaling. We have previously assumed (see footnote 20) that global dose, which integrates dose times area, scales linearly with energy. The CASIM calculations indicate that peak dose, at least in the energy regime considered here, scales differently. The version of CASIM used for heavy ion simulation is very slow and the current uncertainty of collimator loss does not justify the effort required for separate calculations for Au and protons.

63. A. Stevens, S. Musolino, M. Harrison, "Design Criteria for Prompt Radiation on the RHIC Site," Health Physics, 66:3 pp 300-304, 1994.

64. "Safety Analysis Report for the Alternating Gradient Synchrotron," August 11, 1993.

65. "Life Safety Code Analysis, Brookhaven National Laboratory, Building 1002A, RHIC Support Building," September 2, 1994, T. Mc Evaddy.

66. "Life Safety Code Analysis, Brookhaven National Laboratory, Building 1004A, RHIC Support Building," September 14, 1994, T. Mc Evaddy.

67. "Life Safety Code Analysis, Brookhaven National Laboratory, Building 1006A, RHIC Support Building," September 12, 1994, T. Mc Evaddy.

68. "Life Safety Code Analysis, Brookhaven National Laboratory, Building 1008A, RHIC Support Building," October 24, 1994, T. Mc Evaddy.

69. "Life Safety Code Analysis, Brookhaven National Laboratory, Building 1010A, RHIC Support Building," October 7, 1994, T. Mc Evaddy.

70. "Life Safety Code Analysis, Brookhaven National Laboratory, Building 1012A, RHIC Support Building," October 20, 1994, T. Mc Evaddy.

71. "Life Safety Code Analysis, Brookhaven National Laboratory, Building 1000P, RHIC Power Supply Building," October 20, 1994, T. Mc Evaddy.

72. "Life Safety Code Analysis, Brookhaven National Laboratory, Building 1005S, RHIC Collider Center," October 11, 1994, T. Mc Evaddy.

73. "Life Safety Code Analysis, Brookhaven National Laboratory, Building 1005R, RHIC Cryogenic Compressor Wing," January 19, 1995, T. Mc Evaddy.

74. "Life Safety Code Analysis, Brookhaven National Laboratory, Building 1005H, RHIC Compressor Building," October 27, 1994, T. Mc Evaddy.

75. "Life Safety Code Analysis, Brookhaven National Laboratory, Building 1005E, RHIC Injection Power Supply Building," October 5, 1994, T. Mc Evaddy.

76. "Life Safety Code Analysis, Brookhaven National Laboratory, Building 1007E, RHIC Injection Power Supply Building," October 27, 1994, T. Mc Evaddy.

77. "Life Safety Code Analysis, Brookhaven National Laboratory, Building 1002B, RHIC Service Building," October 3, 1994, T. Mc Evaddy.

78. "Life Safety Code Analysis, Brookhaven National Laboratory, Building 1004B, RHIC Service Building," October 3, 1994, T. Mc Evaddy.

79. "Life Safety Code Analysis, Brookhaven National Laboratory, Building 1006B, RHIC Service Building," October 3, 1994, T. Mc Evaddy.

80. "Life Safety Code Analysis, Brookhaven National Laboratory, Building 1008B, RHIC Service Building," January 24, 1995, T. Mc Evaddy.

81. "Life Safety Code Analysis, Brookhaven National Laboratory, Building 1010, RHIC Magnet Enclosure Building," October 7, 1994, T. Mc Evaddy.

82. "Life Safety Code Analysis, Brookhaven National Laboratory, Building 1012, RHIC Magnet Enclosure Building," October 20, 1994, T. Mc Evaddy.

83. Presentation to the Radiation Safety Committee on April 3, 1996 by A. J. Stevens in RSC file. [The value in this reference is 6.5 mrem/yr at 13 ft of earth cover, which scales to 0.8 mrem/yr at 17.5 ft.]

84. Peter J. Gollon, "Amendment to Shielding of Multi-Leg Penetrations into the RHIC Collider," AD/RHIC/RD-76A, July 1996.

85. Methane Heat of Combustion 995 BTU/ft^3, CRC Handbook of Chemistry and Physics.

86. http://www.vogelzang.com/salamander2.htm , 155,000 BTU/hr.

87. G. Behrsing,"Calculated Flammability Limits of Methane-Argon Gas Mixtues," LBL note: M5659, Jan. 28, 1981.

    H.F. Coward and G.W. Jones, "Limits of Flammability of Gases and Vapors, Bulletin 503, Bureau of Mines, 1952.

    B. Lewis and G. Von Elbe, "Combustion, Flames and Explosions of Gases," Academic Press Inc., New York, 1961.

    M.G. Zabetakis, "Flammability Characteristics of Combustaible Gases and Vapors," Bulletin 627, Bureau of Mines, 1965.